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TESTS OF A THERMAL ICE-PREVENTION SYSTEM FOR A WING LEADING-EDGE LANDING-LIGHT INSTALLATION

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, U. S. Army Air Forces

TESTS OF A THERMAL ICE-PREVENTION SYSTEM FOR A WING LEADING-EDGE LANDING-LIGHT INSTALLATION

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SUMMARY

The thermal ice-prevention system of a bomber-type airplane has been modified in an attempt to provide protection against ice and fog formations on the transparent fairing over the landing light in the wing leading edge. A comparison of the design performance with the actual performance measured on the ground and in flight in dry air indicated that the prediction of the outer-surface heat-transfer coefficient was satisfactory, but that the inner-surface heat-transfer coefficient was approximately four times as large as expected. This difference is attributed to the impinging action of the heated air on the transparent fairing, a factor which could not be evaluated in the idealized design analysis. The failure of the transparent plastic fairing due to overheating, coupled with the return of the airplane to service, precluded modification of the system and further testing.

INTRODUCTION

As an extension to the application of thermal ice-prevention systems, which up to the present have been concerned only with the prevention of ice on the metallic surfaces of the wings and empennage, an investigation of a method of ice prevention on wing-leading-edge landing lights has been conducted. Ice prevention of such installations is necessary because the light beam is interrupted by ice formations on the outer surface of the leading-edge transparent fairing and by fog on the inner surface. In addition, the ice destroys the aerodynamic efficiency in the region of the wing surrounding the light.

The analytical part of the investigation was reported in reference 1 wherein it was indicated that the wing thermal ice-prevention system could be utilized to afford protection for the light installation. The current investigation was conducted on a bomber-type airplane and includes ground and flight tests in dry

air to provide experimental verification of the analysis.

DESCRIPTION OF THE INSTALLATION

Photographs of the standard leading-edge landing-light installation in the test airplane and of the test installation, modified in accordance with reference 1, are shown in figures 1(a) and 1(b), respectively. A plan view of the test installation showing its relationship to the outer-wing-panel thermal ice-prevention system is presented in figure 2.

The analysis of reference 1 indicated that a reduction in the space between the sealed-beam light and the leading edge would be necessary to prevent the formation of ice on the transparency, and that a reduction in the surface area of the transparent fairing would be desirable from strength considerations. Accordingly, the landing light was moved forward from a location at approximately 6 percent chord to about 3 percent chord and the surface area of the transparent fairing reduced in accordance with reference 2, which governs the area of the light beam.

The landing light was incorporated into the existing wing de-icing system by extending the spanwise plenum through the wing splice into the light well, as shown in figure 2. The heated-air supply duct which originally bypassed the light was directed to the inboard end of the extended plenum at station 18. A double skin was extended to the region around the transparent fairing, as shown in figure 3.

Instrumentation included a venturi meter and shielded thermocouple, both located in the duct supplying heated air from the heat exchanger, as shown in figure 2, and five small-gage wire thermocouples mounted on each surface of the plastic, as shown in figure 3.

The transparent fairing was fabricated from 1/8-inch-thick CR-39 plastic, since that plastic retains its strength at higher temperatures than any other plastic known to be available.

TESTS AND RESULTS

Flight and ground tests were conducted with the test installation to obtain dry-air performance data. The flight-test data were taken during (1) normal- and rated-power climbs to determine if the plastic became overheated, (2) cruise and high power in level flight at 5,000, 10,000, and 18,000 feet pressure altitudes to check the design analysis, and (3) descent to determine if the plastic received sufficient heat under this low-power condition. The value of thermal conductivity of the CR-39 plastic fairing was determined

experimentally at the Ames Aeronautical Laboratory to be approximately 1.75 Btu per hour, square foot, $^{\circ}$F per inch.

Table I contains a summary of the results of tests at the conditions tested. Average temperatures on the surfaces of the plastic were obtained by means of the thermocouples shown in figure 3. Heat-transfer rates through the plastic were obtained from the average temperature gradients, thickness, and thermal conductivity of the CR-39 plastic fairing. The inner- and outer-surface heat-transfer coefficients were calculated from the heat-transfer rate, and from the difference between the average surface temperatures and adjacent air temperatures.

A comparison of the experimental results at two heated-air-flow rates with the analytical results of reference 1 is presented in table II and in figure 4 where surface-temperature profiles are plotted.

A comparison is made in table III of the values measured during rated-power climbs at two heated-air flow rates. The plastic fairing failed under the condition of run D, as shown in figure 5.

DISCUSSION

A comparison of the analytical and experimental results of figure 4 shows the surface temperatures of the plastic to exceed the predicted values even though test A of table II shows the flow rate of heated air to be about 60 percent of the design flow rate. Although the outer-surface heat-transfer coefficient is of the same order of magnitude as the predicted value, the inner-surface coefficient is about four times as large for comparable flow rates as its predicted value. This difference may be attributed to the impinging action of the heated air on the plastic, a factor inherent in the test installation, since higher heat-transfer coefficients are known to result when air impinges on a surface rather than when it flows parallel to the surface. In the analysis, which was based upon the flow in straight pipes, no account was taken of this factor.

The heat-transfer rates and temperatures shown in table I, being of the same order of magnitude as those in systems which have been successfully tested in ice, are considered adequate for ice prevention under most conditions.

The upper temperature limit of a properly mounted plastic fairing lies between the conditions shown in tests C and D of table III since failure occurred under the conditions of test D. Accordingly, the maximum temperature of the inner surface of the CR-39 plastic should not exceed 220° F when transferring a quantity of heat corresponding to an average temperature drop of 100° F

through the plastic.

A previous failure which occurred during a ground runup is attributed to faulty mounting. Insufficient clearance had been allowed around the bolt holes to allow for expansion of the plastic.

Since the wing ice-prevention system requires a larger amount of heated air than was obtained in the present tests, the landing-light installation must be modified so as to prevent overheating of the plastic at the required flow rate. Such modifications include (1) a redirection of the supply duct to allow the heated air to flow parallel to the surface of the plastic fairing, (2) an enlargement of the cross-sectional area of the plenum in the region of the plastic, and (3) the installation of a bypass duct to allow a portion of the heated air to flow around the landing light. The first two modifications reduce the heat-transfer coefficient on the inner surface of the plastic, while the third allows the larger flow rate to be supplied to the wing ice-prevention system without modifying the landing-light system.

CONCLUSIONS

The following conclusions are drawn and recommendations are made:

1. Satisfactory agreement was obtained between analytical and experimental values of the outer-surface heat-transfer coefficient; however, the inner-surface heat-transfer coefficient was four times as large as the predicted value, the difference being attributed to the impinging action of the heated air on the surface of the transparent fairing.

2. The rate of heat transfer and the outer-surface temperatures are considered to be adequate for the prevention of ice on the landing-light fairing.

3. The maximum inner-surface temperature of the CR-39 plastic fairing should not exceed 220° F when the average temperature gradient through the plastic is 100° F.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., December 11, 1944.

REFERENCES

1. Hillendahl, Wesley H.: Analysis of a Thermal Ice-Prevention System for Wing Leading-Edge Landing-Light Installations. NACA ARR No. 4A11, 1944.

2. Anon.: General Specifications for Installation of Lighting in Aircraft. U.S. Army Specification No. 94-32265-B. Aug. 10, 1942.

TABLE I.– COMPARISON OF TEST RESULTS AT SEVERAL ALTITUDES AND FLIGHT CONDITIONS

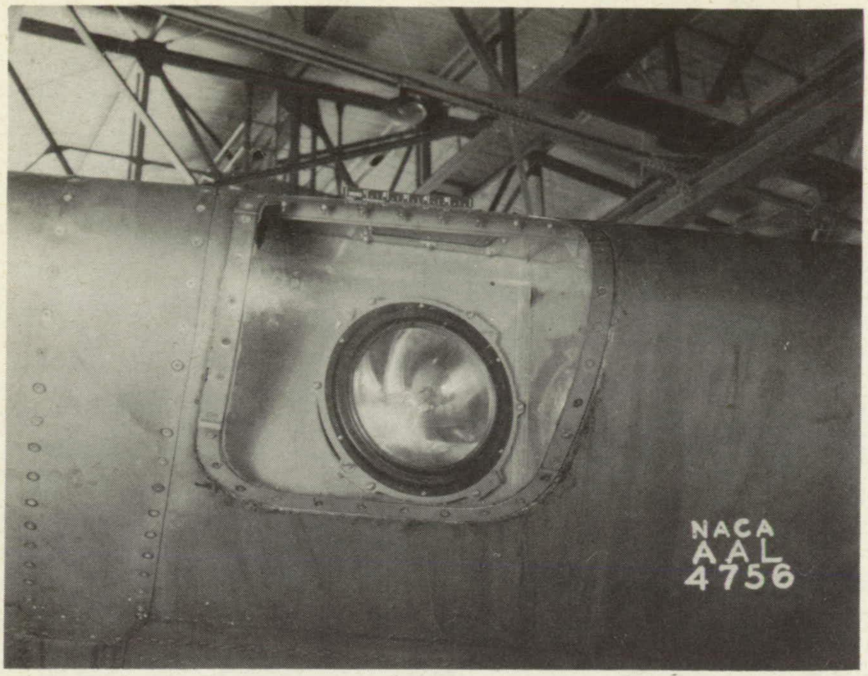
Flight condition	Normal-power climb	Rated-power climb	Level flight	Level flight	Level flight	Descent	Ground	Ground
Pressure altitude, ft	10-13,000	9-12,000	18,000	10,000	5000	15-13,000	0	0
Indicated airspeed, mph	145	135	153	155	155	171	0	0
Free-air temperature, $^{\circ}F$	48	56	27	55	73	45	66	66
Heated-air temperature, $^{\circ}F$	298	318	305	290	259	246	207	165
Heated-air-flow rate, lb/hr	1620	1520	1550	1820	1870	1870	1000	695
Average temperature of inner surface of plastic, $^{\circ}F$	215	225	210	215	210	180	150	125
Maximum temperature of inner surface, $^{\circ}F$	225	235	230	235	220	195	---	---
Average temperature of outer surface, $^{\circ}F$	115	115	110	115	130	105	95	90
Maximum temperature of outer surface, $^{\circ}F$	125	130	115	130	140	110	---	---
Average temperature gradient through plastic fairing, $^{\circ}F$	105	110	100	100	80	80	53	40
Heat-transfer rate through plastic fairing, Btu/hr, sq ft	1450	1550	1400	1400	1100	1100	750	550
Inner-surface heat-transfer coefficient, Btu/hr, sq ft, $^{\circ}F$	18	17	15	19	22	17	13	14
Outer-surface heat-transfer coefficient, Btu/hr, sq ft, $^{\circ}F$	22	26	17	23	19	18	26	23

TABLE II.– COMPARISON OF ANALYTICAL AND TEST RESULTS

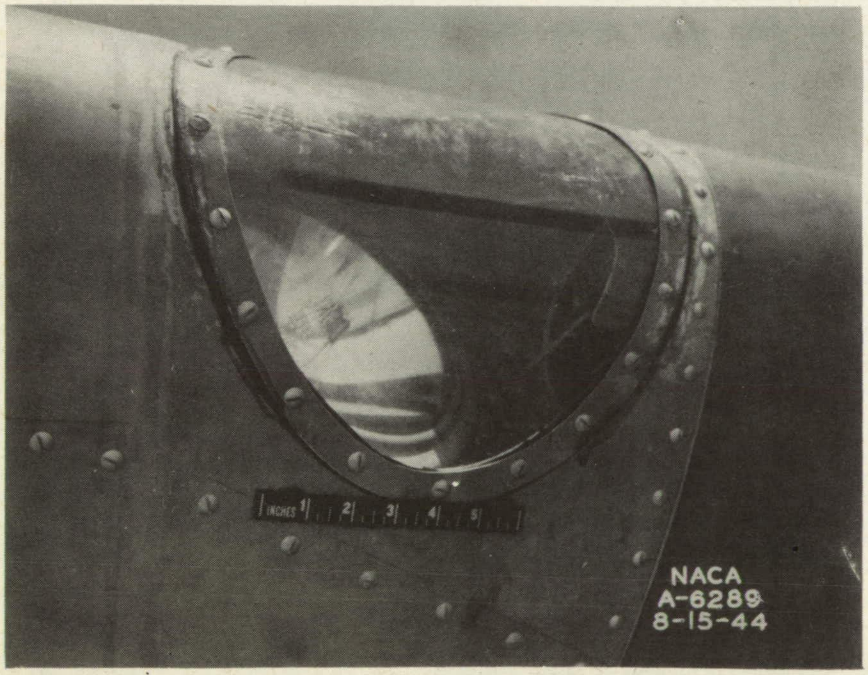
	Analytical	Test A	Test B
Flight condition	Level flight	Level flight	Level flight
Pressure altitude, ft	18,000	18,000	18,000
Indicated airspeed, mph	155	153	155
Free-air temperature, °F	30	27	32
Heated-air temperature, F	320	305	315
Total flow rate from heat exchanger, lb/hr	2730	3490	3280
Flow rate of heated air to landing light, lb/hr	2730	1550	1840
Average temperature of inner surface of plastic fairing, °F	165	210	235
Maximum temperature of inner surface, °F	185	230	270
Average temperature of outer surface, °F	90	110	110
Maximum temperature of outer surface, °F	120	115	127
Average temperature gradient through plastic fairing, °F	70	100	120
Heat-transfer rate through plastic fairing, Btu/hr, sq ft	980	1400	1680
Inner-surface heat-transfer coefficient, Btu/hr, sq ft, °F	6.5	15	21
Outer-surface heat-transfer coefficient, Btu/hr, sq ft, °F	16	17	21

TABLE III.- COMPARISON OF RESULTS AT MAXIMUM POWER

	Test C	Test D
Flight condition	Rated-power climb	Rated-power climb
Pressure altitude, ft	10,000	10,000
Indicated airspeed, mph	135	135
Free-air temperature, °F	55	25
Heated-air temperature, °F	320	350
Total flow rate from heat exchanger, lb/hr	4090	3210
Flow rate of heated air to landing light, lb/hr	1520	1710
Average temperature of inner surface of plastic, °F	225	270
Maximum temperature of inner surface, °F	235	285
Average temperature of outer surface, °F	115	135
Maximum temperature of outer surface, °F	130	155
Average temperature gradient through plastic fairing, °F	110	130
Average heat-transfer rate through plastic fairing, Btu/hr, sq ft	1550	1800



(a) Standard installation.



(b) Installation fitted with ice-prevention equipment.
Figure 1.- Landing-light installation on test airplane.

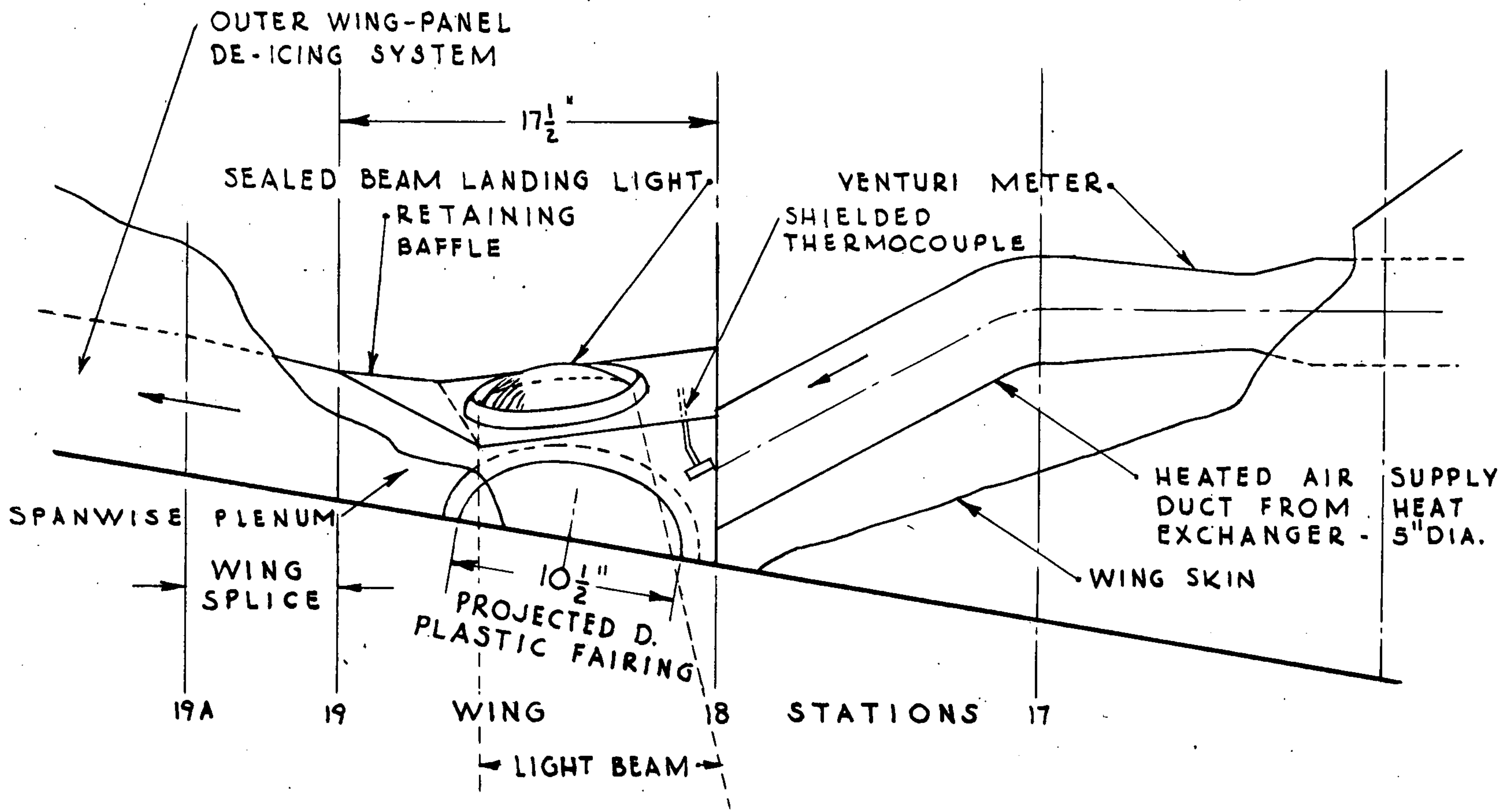


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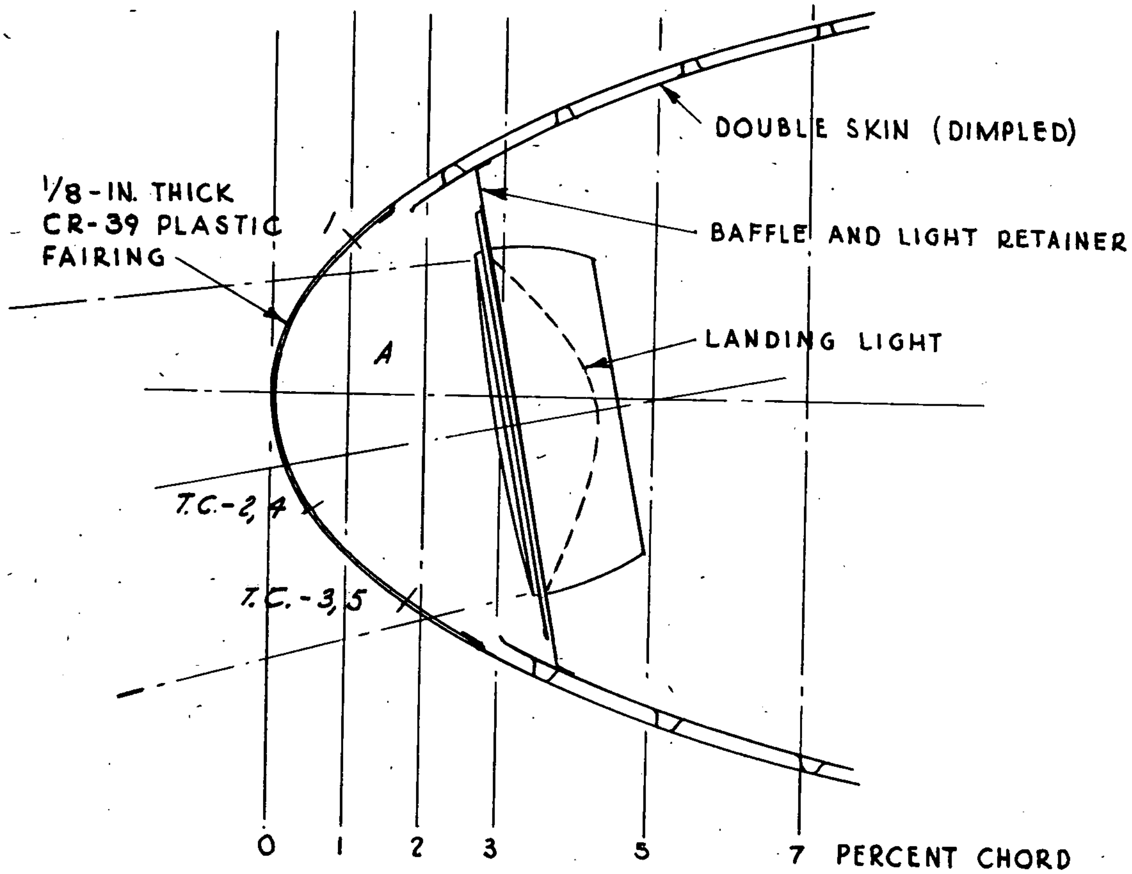
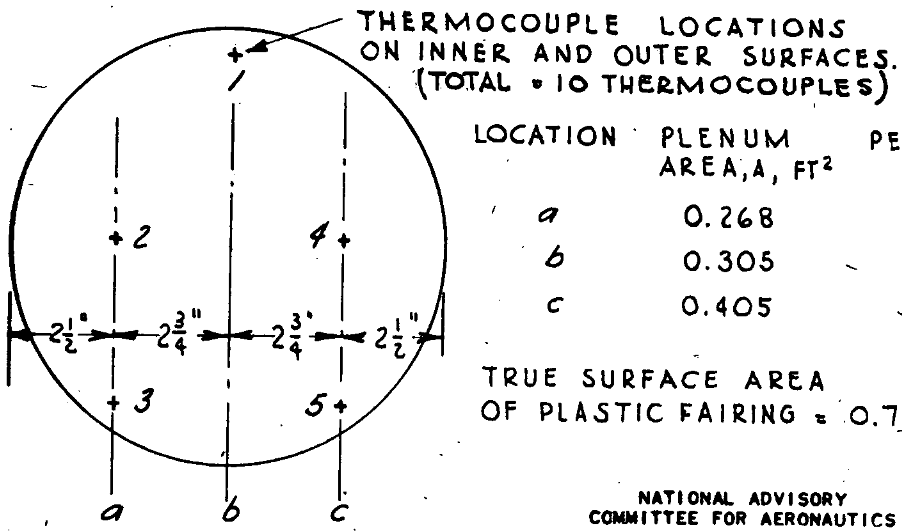
FIGURE 2.- LANDING-LIGHT INSTALLATION ON TEST AIRPLANE EQUIPPED FOR THERMAL ICE PREVENTION.





PROJECTED SURFACE OF PLASTIC FAIRING

LOCATION	PLENUM AREA, A, FT²	PERIMETER FT
a	0.268	2.46
b	0.305	2.68
c	0.405	2.87

TRUE SURFACE AREA OF PLASTIC FAIRING = 0.715 FT²

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FIGURE 3.- PLENUM AREA AND THERMOCOUPLE LOCATIONS ON PLASTIC FAIRING.

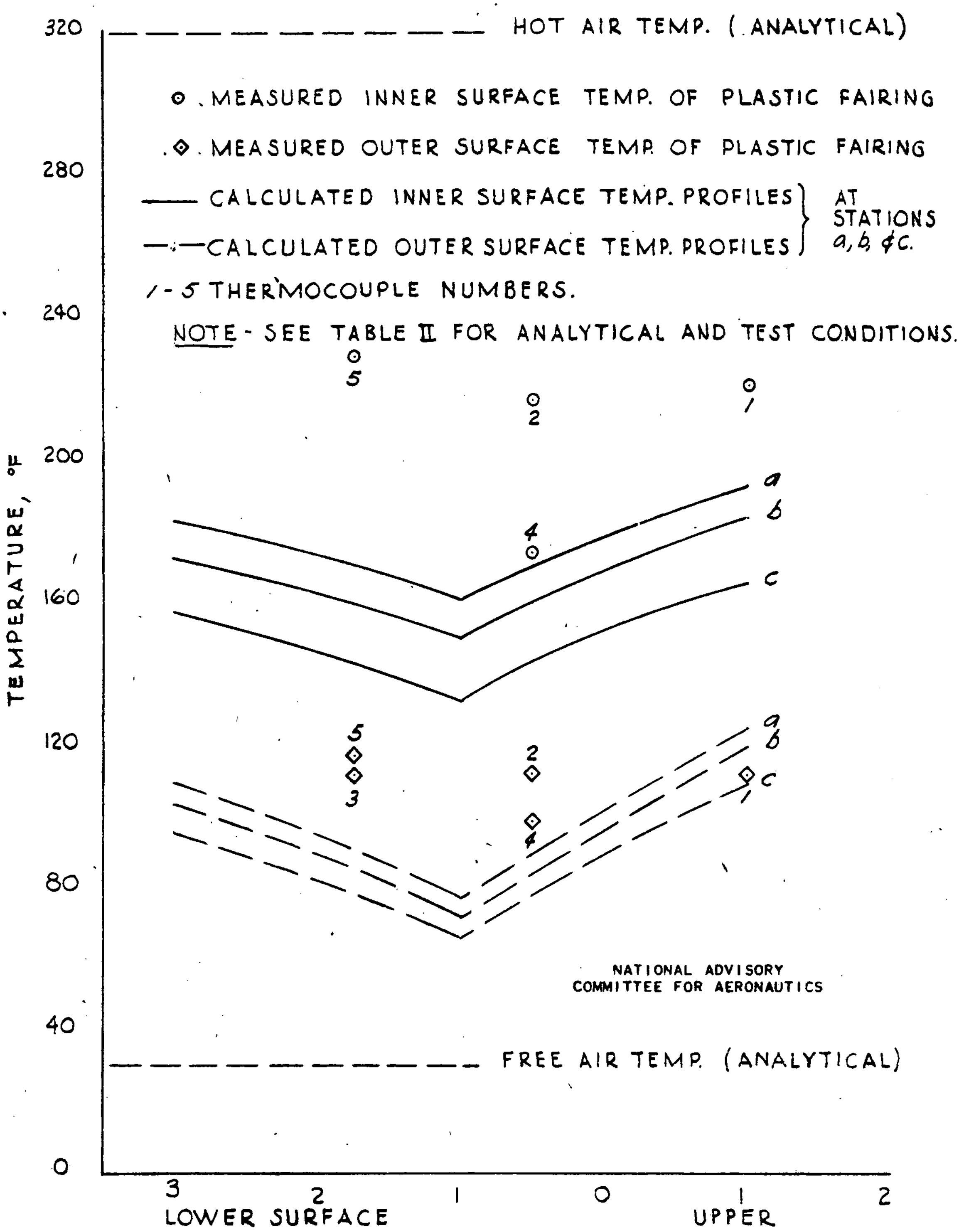

FIGURE 4. - COMPARISON OF ANALYTICAL AND TEST VALUES OF SURFACE TEMPERATURES OF PLASTIC FAIRING.

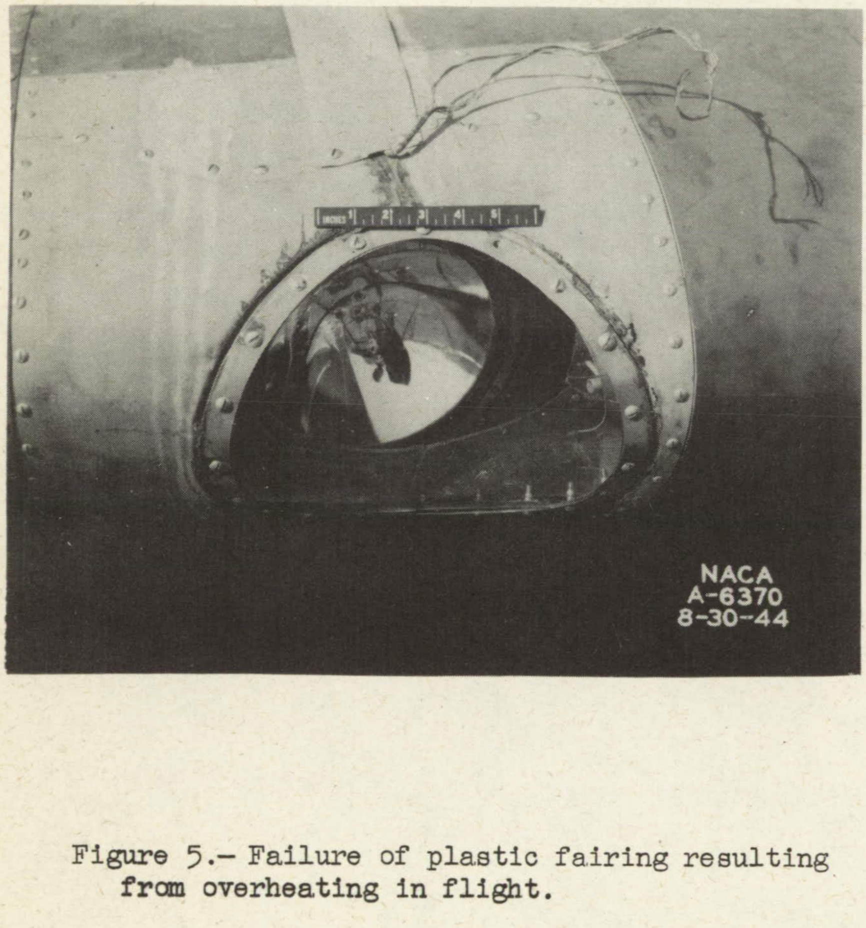

Figure 5.- Failure of plastic fairing resulting from overheating in flight.